

# **Plankton Distribution in Internal Waves in Massachusetts Bay**

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## **LONG-TERM GOALS**

Our long-term goals are describing and understanding the mechanisms responsible for plankton accumulation and transport in large amplitude internal waves.

## **OBJECTIVES**

The general objective of our research is to observe the effects of tidally generated undular bores on near-surface plankton distribution. The particular objectives are (1) to determine the spatial scales of plankton distribution compared to the physical features before, during and after the internal tidal bores, and (2) to resolve whether plankton is concentrated by the physical characteristics of the bores. If there is a pattern in the plankton distribution associated to the bore, then another objective is (3) to determine whether plankton accumulation is dependent on plankton behavior, and whether, and to resolve whether taxa redistribute differentially in specific regions of the bore.

## **APPROACH**

We are using a combined observational and theoretical approach (Pineda et al., 2002). Our observational program includes following internal bores as they propagate from Stellwagen bank to Scituate, in Massachusetts Bay. The bores are sampled with a shipboard Doppler current meter (velocity and backscatter) and a towed video plankton recorder (VPR). In addition to capturing images, the VPR records depth, conductivity, temperature, fluorescence, light attenuation and Photosynthetically Active Radiation. The program also includes observing the bores with moored instruments, including a moored video plankton observatory system (“AVPPO”), temperature

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moorings, and Doppler current meter profilers. Our observations on the particle accumulation by the bores will be contrasted with an internal bore model (Scotti and Beardsley, *subm.*) The bore model will also be used to guide our observational program. In general, Pineda and Gallagher are responsible for the observational portion of the program, while Scotti is in charge of the theoretical aspect.

## **WORK COMPLETED**

The fieldwork component consists of two cruises, one in 2001 and another in 2002. The 2001 cruise sailing date, originally scheduled for September 10, was moved to September 12, due to an unforeseeable circumstance that prevented the Captain of the R/V Connecticut from being available on the planned date. Poor sea conditions forced us to return to port two days earlier than planned. The first cruise was originally envisioned as a test for our deployment and sampling strategies, and the objectives of the second year were to complete observations necessary to address our scientific questions. Despite the reduced available time in 2001, we were nonetheless able to acquire a significant wealth of data. On our 2001 cruise we deployed five temperature moorings, located at 25 (1 mooring), 30 (1) and 45 (3) m water depth, and two Doppler current profilers at 25 and 45 m. The instruments acquired high frequency temperature and currents time series. We also obtained hourly profiles from seabed to surface of plankton, temperature, conductivity, fluorescence, light attenuation at 5 frequencies (AC-9), and up and down-welling irradiance with the AVPPO. We also sampled about 14 internal bore fronts as they propagated westward from Stellwagen bank, both during daytime and nighttime. Sampling was completed with the VPR (plankton, temperature, conductivity and depth) and with a shipboard 600 kHz Doppler current meter (backscatter, velocity.) The number of passes perpendicular to the wave crest ranged from 4 to 15.

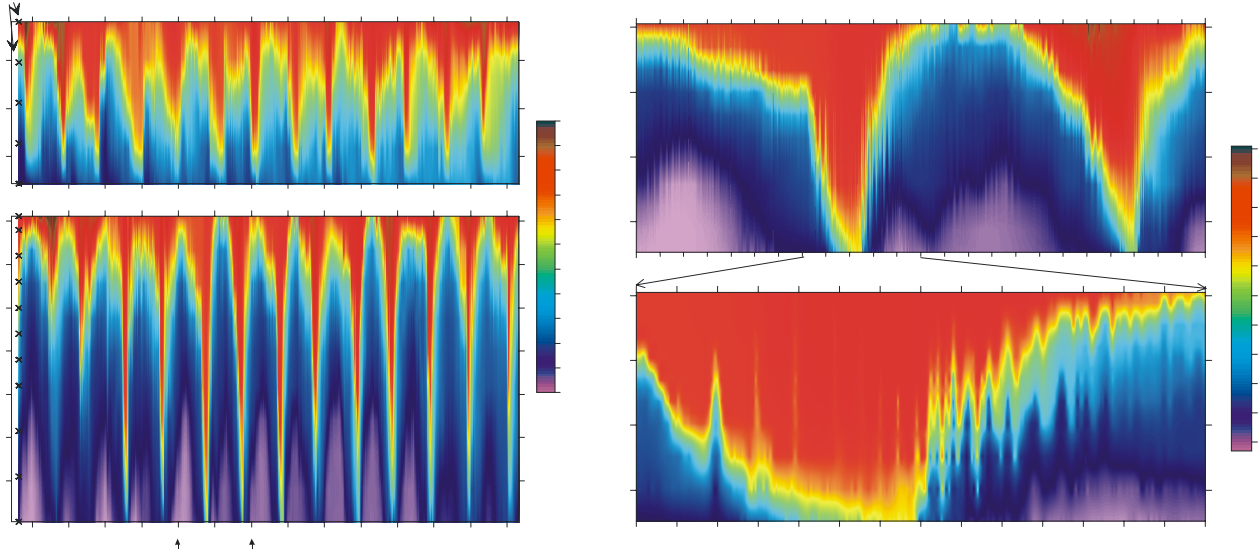
The first field campaign was completed in September of 2001. The second is scheduled from 28 September to 10 October 2002, which is after the due date of this report so we do not present those results

On the modeling side, we have completed the two-dimensional model of the internal tide in Massachusetts Bay.

## **RESULTS**

Temperature moorings recorded a very energetic internal tide throughout the entire water column at 25 and 45 m (Fig. 1). Preliminary analyses suggest that the higher-frequency motions (periods less than 10s of minutes) were more prominent at the 45 m than at the 25 m mooring. We also observed the evolution of bores with trailing high-frequency internal waves, in ~80 m water, into bores with no trailing waves at ~30-40 m water. The numerical model shows that the sloping bottom to the west of Stellwagen Basin, during the majority of the environmental conditions observed, acts as a low-pass filter for the internal bore. The high-frequency train of solitary waves trailing the initial depression does not propagate beyond the 30 m isobath, but dissipates due to instabilities. However, the leading edge of the bore is able to move up-shelf towards shallow waters. Thus, sharp semidiurnal variability occurs at both depth stations, but the associated high-frequency variability occurs mostly at the 45 m depth station.

25 m water depth (mooring 3, upper left panel) and 45 m (mooring 1c, all other panels). The panels to the right are amplifications of the bottom left panel.

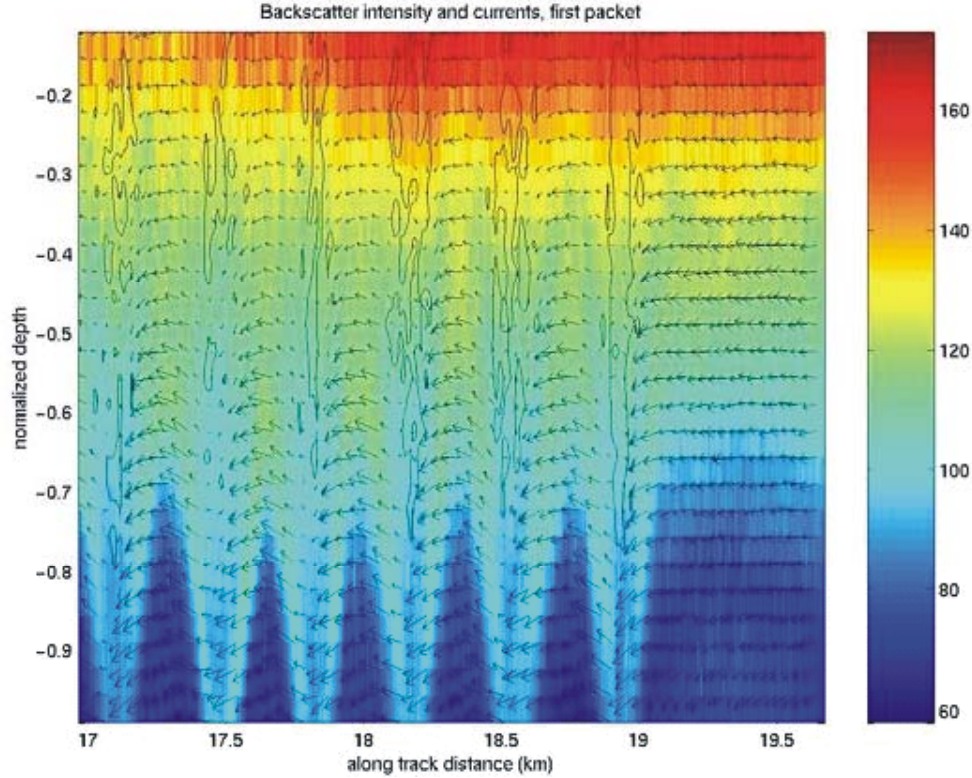


**Figure 1. Time series of interpolated temperature at 25 (upper left) and 45 m (bottom left). The right panels are amplifications of the bottom left panel.**

*[The left panels show that the whole water column at 25 and 46 m oscillates from warm to cold about every 12.4 hours during the entire sampling period (from day of the year ~256 to 262). The right panels show that at 45 m, when the temperature is warming, there are higher-frequency (few minutes) internal waves associated to the 12.4 h variability. Similarly, when the water column is cooling, high-frequency oscillations lead this cooling.]*

We followed packets of internal waves as they propagated from Stellwagen Bank towards Scituate. On several occasions, zones of high backscatter were associated with internal bore depressions, and these zones accompanied bores for several hours as they propagated onshore. Maximum velocities in the direction of propagation coincided with zones of highest backscatter.

According to our model, the waves are generated by the interaction of the barotropic tide with Stellwagen Bank. During the tidal ebb phase, the supercritical flow over the bank creates a standing pool of light surface-water on the offshore side of the bank. When the tide reverses, the pool is released. The initial bore evolves under the action of nonlinearity and dispersion into the undular bore observed in the bay. The model helps to explain the modification of the wave trains as they approach the shoaling area. The preliminary observational data agree with the theoretical predictions. We have also conducted a preliminary analysis of the physical characteristic of a few packets. The propagation direction and speed were estimated based on the time between successive encounters and on the direction of the near surface current in the waves. Figure 2 shows one of such packets. The current is measured relative to a frame of reference moving with the packet. Current speeds are very close to the phase speed, and there are clearly marked recirculating regions in the first four pulses. If the analysis of the plankton distribution within the pulses shows taxa not found ahead of the packet, we have a solid case for the existence of waves with a trapped core, which, as far as we know, have never been observed in the ocean (though they have been predicted theoretically, e.g. Lamb 2002).



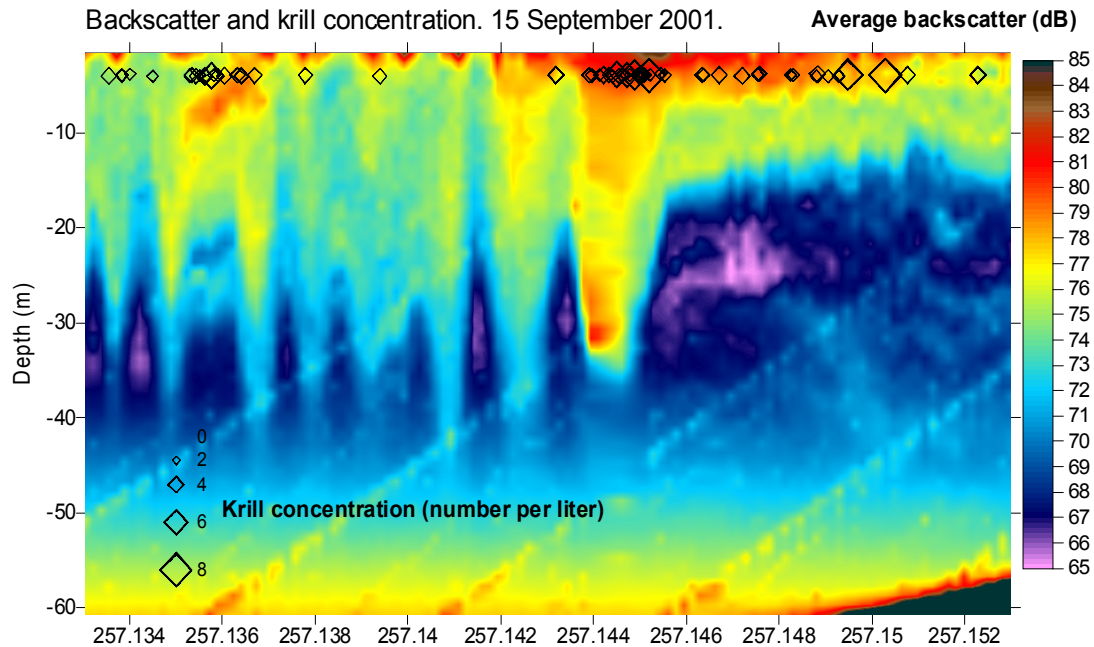
**Figure 2. Currents and interpolated backscatter intensity (uncorrected for depth) measured across a train of nonlinear internal waves propagating in Massachusetts Bay on 15 September 2001 (the leading edge of the packet was reached at 01:12 GMT). The direction of propagation of the packet was estimated to be 225°T, at a speed of 45 cm/s. The observed currents are shown relative to an observer moving with the phase speed of the packet. Regions of recirculating flow are visible in the first four pulses. Closed contours indicate areas where current speed was larger than phase speed.**

**The same packet, a few hours later, is shown in Figure 3.**

**[At crests and above crests of the internal waves circulation is from right to left (opposite in direction from the presumed direction of propagation of the train of nonlinear internal waves). At the wave depressions right to left arrows disappear or weakly reverse, indicating that the current speed in the direction of front propagation is very close to the propagation speed of the waves.]**

We observed plankton with the VPR at a constant depth and by yo-yoing. Our undulating VPR was sometimes incapable of yo-yoing rapidly enough to resolve the high-frequency internal waves. In our next cruise we will implement a different version of the VPR that is for faster yo-yoing. The VPR tapes are being processed in several steps, corresponding to different size classes of zooplankton. We have results from the first analysis step, for the largest zooplankton size-class, with medium- and smaller- sized plankton currently being processed. The largest size class includes the krill *Thyanessa rauchii* (sp?), a taxon we observed in our night samples. The constant-depth samples reveal high concentration of krill in the depression at the leading edge of the bores (Fig. 3). We also observed high concentration in other areas away from the depression, but the occurrence of high concentrations at the leading edge





**Figure 3. Interpolated backscatter and krill concentration in an internal bore front in Massachusetts Bay. Note the high concentration of krill in the leading depression. Krill were observed with the VPR maintained at a constant depth (~-4 m) while backscatter was recorded with the ships' Doppler current meter. The ship is heading towards the south-west. The transect was 5.2 km long and lasted 29 minutes.**

*[The figure shows a layered horizontal backscatter pattern from time day of the year ~257.146 to time ~257.152. After 257.146 the backscatter patterns reveal eight waves of depression. The patterns in the backscatter reveal that the leading depression is about 20 m in wave height. Krill concentration is depicted with proportionally sized diamonds, and concentrations range from 0 to 8 individuals per liter. Most samples contain zero concentrations. The largest number of non-zero values occurs in the leading depression.]*

was a recurrent pattern in two events. To determine whether behavior of krill inside and outside the areas of depressions differs, we will compare the orientation of krill, as a proxy for behavior in the two areas. If behavior is involved in the concentration of krill at the bore depression, we expect different orientation in and outside the depressions. Finally, we will also analyze orientation of middle- and small-sized plankton.

## IMPACT/IMPLICATIONS

Our research will shed light on the formation and persistence of zooplankton patchiness by internal bores and waves, and whether zooplankton behavior influences this pattern.

## TRANSITIONS

None

## **RELATED PROJECTS**

This project is a new start. Scotti's modeling paper is related to a USGS project on internal waves in Massachusetts Bay.

## **REFERENCES**

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Scotti A. and R. Beardsley, subm. Large internal waves in Massachusetts Bay. Part 1: Modeling generation, propagation and shoaling. Submitted to JGR.

## **PUBLICATIONS**

Scotti A. and R. Beardsley, subm. Large internal waves in Massachusetts Bay. Part 1: Modeling generation, propagation and shoaling. Submitted to JGR.